FINE STRUCTURE OF ALPHA-DECAY FROM THE TIME-DEPENDENT PAIRING EQUATIONS

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Alpha-decay

In the theory of alpha decay, a preformed cluster penetrates essentially a Coulomb barrier. The microscopic part of the process concerns the modality in which the alpha particle is born. This preformation is usually calculated as an overlap between the parent and the final configurations.

If an extreme saturation of the nuclear matter is assumed, the states of all nucleons depend on the boundaries of the many body potential, that is, on the nuclear shape. If an alpha is moving to the surface, all single particle states of the compound system are perturbed.

A fission-like formalism in which one follows rearrangement of the single particle states when the boundaries of the system are modified, starting from the ground state and reaching the scission, is envisaged.

The time-dependent pairing equations for odd-nuclear systems are generalized by including the Landau-Zener effect and the Coriolis coupling.

VARIATIONAL METHOD

$$\delta L = \delta\langle\varphi_{IM}|H + H_R - i\hbar\frac{\partial}{\partial t} + H' - \lambda\hat{N}|\varphi_{IM}\rangle,$$

Energy functional

$$|\varphi_{IM}\rangle = \sum_{\Omega,m} c_{\Omega,m}|\varphi_{IM\Omega m}\rangle = \sum_{\Omega,m} c_{\Omega,m} b^{+}_{I,M,\Omega,m} \prod_{(\Omega_1,m_1)\neq(\Omega,m)} \times \left(u_{\Omega_1,m_1(\Omega,m)} + v_{\Omega_1,m_1(\Omega,m)} a^{+}_{\Omega_1,m_1} a^{+}_{\bar{\Omega}_1,m_1}\right)|0\rangle.$$

The trial wave function is expanded as a superposition of Seniority-1 Bogoliubov functions

Rotational functions

$$b^{+}_{I,M,\Omega,m}|0\rangle = \left(\frac{2I+1}{8\pi^2}\right)^{1/2}\left(\frac{\Omega}{|\Omega|}\right)^{I+\Omega} \mathcal{D}^{I}_{M\Omega}(\omega) a^{+}_{\Omega,m}|0\rangle.$$

ENERGY TERMS OF THE FUNCTIONAL

Single-particle Hamiltonian plus pairing

$$H = \sum_{\Omega,m} \epsilon_{\Omega,m} (a^{+}_{\Omega,m} a_{\Omega,m} + a^{+}_{\bar{\Omega},m} a_{\bar{\Omega},m})$$

$$- G \sum_{(\Omega,m)(\Omega_1,m_1)} a^{+}_{\Omega,m} a^{+}_{\bar{\Omega},m} a_{\Omega_1,m_1} a_{\bar{\Omega}_1,m_1},$$

Rotational energy containing the Coriolis coupling

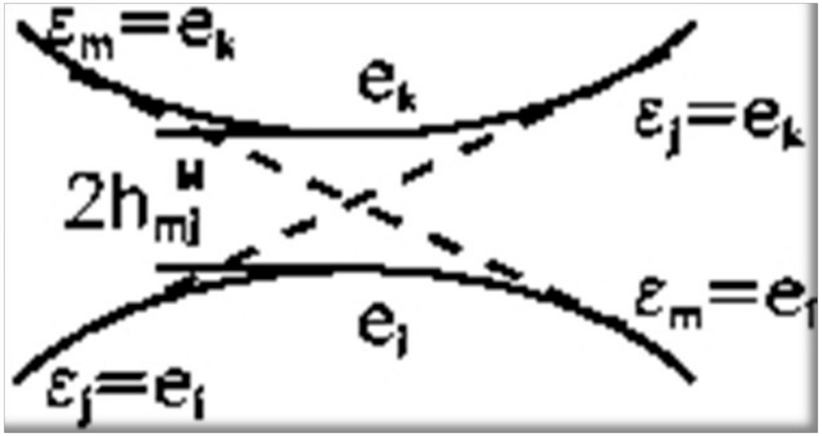
$$H_R = \frac{\hbar^2}{2J}(I^2 - j_z^2) + \frac{\hbar^2}{2J}(j_x^2 + j_y^2) - \frac{\hbar^2}{2J}(j_+ I_- + j_- I_+),$$

Landau-Zener term

$$H' = \sum_{\Omega,m,m'} h_{\Omega,m,m'} \alpha^{+}_{\Omega,m(\Omega,m')} \alpha_{\Omega,m'(\Omega,m)}$$

$$\times \prod_{\Omega',m''} \alpha_{\Omega',m''(\Omega,m')} a^{+}_{\Omega',m''} a_{\Omega',m''} \alpha^{+}_{\Omega',m''(\Omega,m)},$$

The Landau - Zener effect within the single particle model



The wave function of a nucleon Ψ can be formally expanded in a basis of *n* diabatic wave functions

$$\Psi(r,R,t) = \sum_i^n c_i(t)\phi_i(r,R)\exp\left(-\frac{i}{\hbar}\int_0^t \epsilon_{ii}dt\right)$$

Where the matrix elements with the diabatic states ***Φ*** are

$$\epsilon_{ij} = <\phi_i \mid H \mid \phi_j>$$

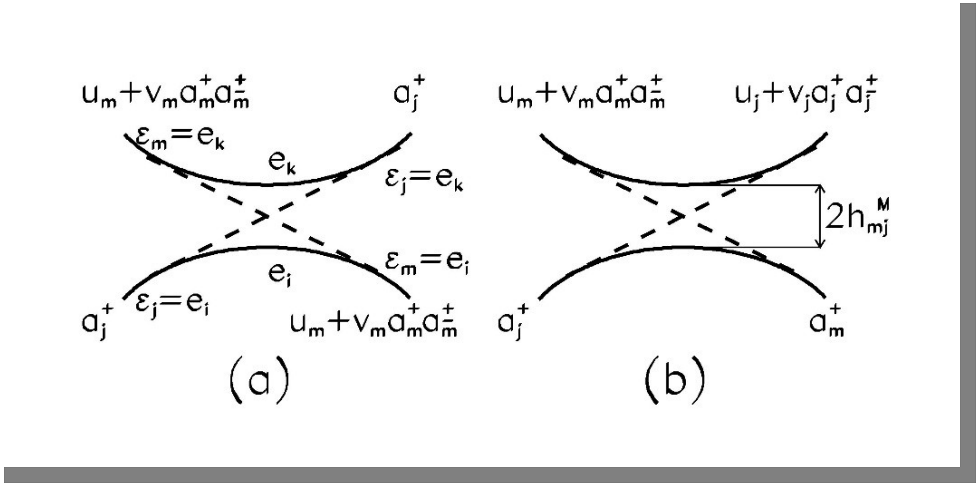
Here *H* is the Hamiltonian.
Inserting ***Ψ*** in the time-dependent Schrodinger equation

$$\left\langle \phi_i \mid H - i\hbar\frac{\partial}{\partial t} \mid \Psi \right\rangle = 0$$

We obtain a system of coupled differential equations that determine the amplitudes c_i

$$\dot{c}_i = \frac{1}{i\hbar}\sum_{j\neq i}^n c_j\epsilon_{ij}\exp\left(-\frac{i}{\hbar}\int_0^t(\epsilon_{jj}-\epsilon_{ii})dt\right)$$

SUPERFLUID SYSTEMS



$$\begin{aligned}
\alpha_k &= u_k a_k - v_k a_{\bar{k}}^+; \\
\alpha_{\bar{k}} &= u_k a_{\bar{k}} + v_k a_k^+; \\
\alpha_k^+ &= u_k a_k^+ - v_k^* a_{\bar{k}}; \\
\alpha_{\bar{k}}^+ &= u_k a_{\bar{k}}^+ + v_k^* a_k;
\end{aligned}$$

$$u_k = u_{\bar{k}}$$
$$v_k = -v_{\bar{k}}$$

Using quasiparticle creation and annihilation operators it is possible to construct operators in order that the nucleon remains on the same adiabatic level

For diabatic states, the second case (b) can be obtained within an operator of the type:

$$O_{mj} = \alpha_{\bar{m}}^+ \alpha_{\bar{j}} + \alpha_{\bar{j}}^+ \alpha_{\bar{m}}$$

FUNCTIONAL MINIMIZATION

The independent variables are $c_{\Omega m}$, u_k, v_k and their complex conjugates

$$
\begin{aligned}
&\langle \varphi_{IM} | H + \frac{\hbar^2}{2J}(I^2 - j_z^2) - \frac{\hbar^2}{2J}(j_+ I_- + j_- I_+) - i\hbar \frac{\partial}{\partial t} + H' - \lambda N | \varphi_{IM} \rangle \\
&= \sum_{\Omega,m} |c_{\Omega,m}|^2 \Bigg\{ 2 \sum_{(\Omega',m')\neq(\Omega,m)} |v_{\Omega',m'(\Omega,m)}|^2 (\epsilon_{\Omega',m'} - \lambda) + (\epsilon_{\Omega,m} - \lambda) \\
&\quad - G \Bigg| \sum_{(\Omega'm')\neq(\Omega,m)} u_{\Omega',m'(\Omega,m)} v_{\Omega',m'(\Omega,m)} \Bigg|^2 - G \sum_{(\Omega',m')\neq(\Omega,m)} |v_{\Omega',m'(\Omega,m)}|^4 \Bigg\} + \frac{\hbar^2}{2J} \sum_{\Omega,m} |c_{\Omega,m}|^2 [I(I+1) - \Omega^2] \\
&\quad - \frac{\hbar^2}{2J} \Bigg\{ \sum_{\Omega} \sum_{m',m} c^*_{\Omega+1,m'} c_{\Omega,m} [(I-\Omega)(I+\Omega+1)]^{1/2} [u_{\Omega,m(\Omega+1,m')} u_{\Omega+1,m'(\Omega,m)} + v^*_{\Omega,m(\Omega+1,m')} v_{\Omega+1,m'(\Omega,m)}] \\
&\quad \times \langle \Omega+1, m' | j_+ | \Omega, m \rangle T_{\Omega+1,m',\Omega,m} + \sum_{\Omega} \sum_{m',m} c^*_{\Omega-1,m'} c_{\Omega,m} [(I+\Omega)(I-\Omega+1)]^{1/2} \\
&\quad \times [u_{\Omega,m(\Omega-1,m')} u_{\Omega-1,m'(\Omega,m)} + v^*_{\Omega,m(\Omega-1,m')} v_{\Omega-1,m'(\Omega,m)}] \langle \Omega-1, m' | j_- | \Omega, m \rangle T_{\Omega-1,m',\Omega,m} \Bigg\} - i\hbar \sum_{\Omega,m} |c_{\Omega,m}|^2 \\
&\quad \times \Bigg[\sum_{(\Omega',m')\neq(\Omega,m)} \frac{1}{2} (v^*_{\Omega',m'(\Omega,m)} \dot{v}_{\Omega',m'(\Omega,m)} - \dot{v}^*_{\Omega'm'(\Omega,m)} v_{\Omega',m'(\Omega,m)}) \Bigg] - i\hbar \sum_{\Omega,m} c^*_{\Omega,m} \dot{c}_{\Omega,m} + \sum_{\Omega,m,m'\neq m} h_{\Omega,m',m} c^*_{\Omega,m'} c_{\Omega,m}.
\end{aligned}
$$

Equations of Motion

$$
\begin{aligned}
-i\hbar\dot{c}^*_{\Omega,m} &= c^*_{\Omega,m}\Bigg\{2\sum_{(\Omega',m')\neq(\Omega,m)}|v_{\Omega',m'(\Omega,m)}|^2(\epsilon_{\Omega',m'}-\lambda)+(\epsilon_{\Omega,m}-\lambda)\\
&\quad -G\Bigg|\sum_{(\Omega'm')\neq(\Omega,m)}u_{\Omega',m'(\Omega,m)}v_{\Omega',m'(\Omega,m)}\Bigg|^2-G\sum_{(\Omega',m')\neq(\Omega,m)}|v_{\Omega',m'(\Omega,m)}|^4\Bigg\}+\frac{\hbar^2}{2J}c^*_{\Omega,m}[I(I+1)-\Omega^2]\\
&\quad -\frac{\hbar^2}{2J}\Bigg\{\sum_{m'}c^*_{\Omega+1,m'}[(I-\Omega)(I+\Omega+1)]^{1/2}[u_{\Omega,m(\Omega+1,m')}u_{\Omega+1,m'(\Omega,m)}+v^*_{\Omega,m(\Omega+1,m')}v_{\Omega+1,m'(\Omega,m)}]\\
&\quad \times\langle\Omega+1,m'|j_+|\Omega,m\rangle T_{\Omega+1,m',\Omega,m}+\sum_{m'}c^*_{\Omega-1,m'}[(I+\Omega)(I-\Omega+1)]^{1/2}\\
&\quad \times[u_{\Omega,m(\Omega-1,m')}u_{\Omega-1,m'(\Omega,m)}+v^*_{\Omega,m(\Omega-1,m')}v_{\Omega-1,m'(\Omega,m)}]\langle\Omega-1,m'|j_-|\Omega,m\rangle T_{\Omega-1,m',\Omega,m}\Bigg\}\\
&\quad -i\hbar c^*_{\Omega,m}\Bigg[\sum_{(\Omega',m')\neq(\Omega,m)}\frac{1}{2}(v^*_{\Omega',m'(\Omega,m)}\dot{v}_{\Omega',m'(\Omega,m)}-\dot{v}^*_{\Omega'm'(\Omega,m)}v_{\Omega',m'(\Omega,m)})\Bigg]+\sum_{m'\neq m}h_{\Omega,m',m}c^*_{\Omega,m'},
\end{aligned}
$$

$$
\begin{aligned}
-i\hbar\dot{v}^*_{\Omega',m'(\Omega,m)} &= 2v^*_{\Omega',m'(\Omega,m)}(\epsilon_{\Omega',m'}-\lambda)-G\sum_{(\Omega'',m'')\neq(\Omega,m)}\Bigg\{u_{\Omega'',m''(\Omega,m)}v^*_{\Omega'',m''(\Omega,m)}\Bigg(u_{\Omega',m'(\Omega,m)}-\frac{v_{\Omega',m'(\Omega,m)}v^*_{\Omega',m'(\Omega,m)}}{2u_{\Omega',m'(\Omega,m)}}\Bigg)\\
&\quad -u_{\Omega'',m''(\Omega,m)}v_{\Omega'',m''(\Omega,m)}\frac{v^*_{\Omega',m'(\Omega,m)}v^*_{\Omega',m'(\Omega,m)}}{2u_{\Omega',m'(\Omega,m)}}\Bigg\}-2Gv_{\Omega',m'(\Omega,m)}v^*_{\Omega',m'(\Omega,m)}v^*_{\Omega',m'(\Omega,m)}. \qquad (
\end{aligned}
$$

Supplemental condition

$$\frac{i\hbar}{2}\left(v^{*}_{\Omega',m'(\Omega,m)}\dot{v}_{\Omega',m'(\Omega,m)} - \dot{v}^{*}_{\Omega',m'(\Omega,m)}v_{\Omega',m'(\Omega,m)}\right) = 2|v_{\Omega',m'(\Omega,m)}|^2(\epsilon_{\Omega',m'} - \lambda) - 2G|v_{\Omega',m'(\Omega,m)}|^4 + \mathrm{Re}\left\{\Delta^{*}_{\Omega,m}\left(\frac{|v_{\Omega',m'(\Omega,m)}|^4}{u_{\Omega',m'(\Omega,m)}v^{*}_{\Omega',m'(\Omega,m)}} - u_{\Omega',m'(\Omega,m)}v_{\Omega',m'(\Omega,m)}\right)\right\}$$

The many body and the centrifugal energies

$$E_{\Omega,m} = \langle\varphi_{IM\Omega m}|H|\varphi_{IM\Omega m}\rangle = 2\sum_{(\Omega',m')\neq(\Omega,m)}|v_{\Omega',m'(\Omega,m)}|^2(\epsilon_{\Omega',m'} - \lambda) + (\epsilon_{\Omega,m} - \lambda) - \frac{|\Delta_{\Omega,m}|^2}{G} - G\sum_{(\Omega',m')\neq(\Omega,m)}|v_{\Omega',m'(\Omega,m)}|^4,$$

$$\begin{aligned} E^{\mathrm{R}}_{I,\Omega} &= \langle\varphi_{IM\Omega m}|\frac{\hbar^2}{2J}(I^2 - j_z^2)|\varphi_{IM\Omega m}\rangle \\ &= \frac{\hbar^2}{2J}[I(I+1) - \Omega^2], \end{aligned}$$

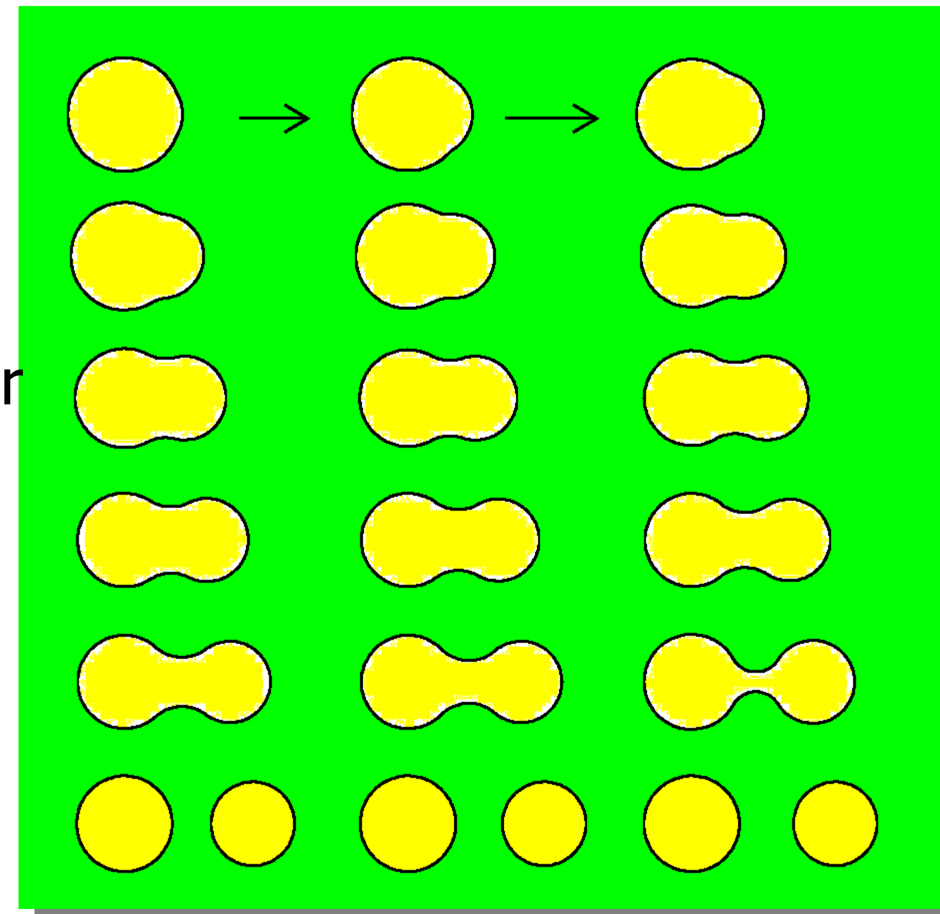
Dissipated energy

An average value of the dissipation energy can be computed from the time dependent pairing equations

$$\Delta E = E_{\Omega m} - E_0$$

FISSION and MACROSCOPIC-MICROSCOPIC MODEL

In fission, the whole nuclear system is characterized by some collective variables which determine approximately the behavior of many other intrinsic variables.



Nuclear shape parametrization

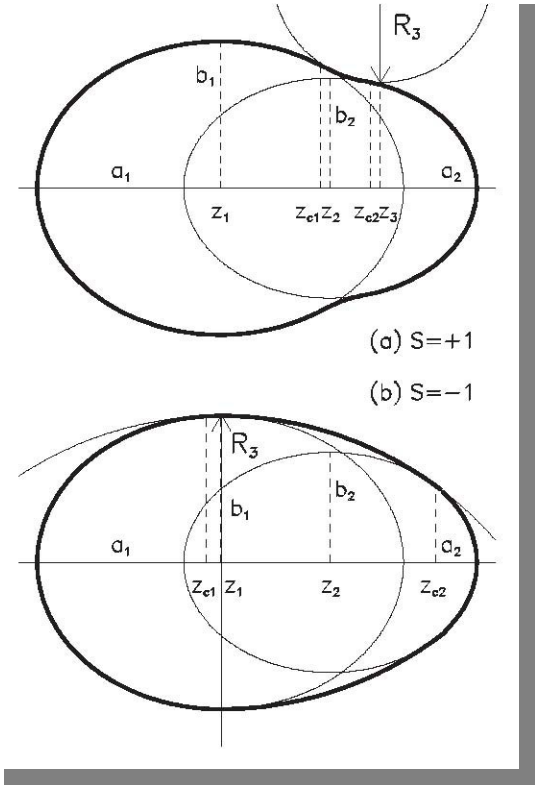
Most important degrees of freedom encountered in fission:

-elongation

-necking-in

-mass-asymmetry

-fragments deformations



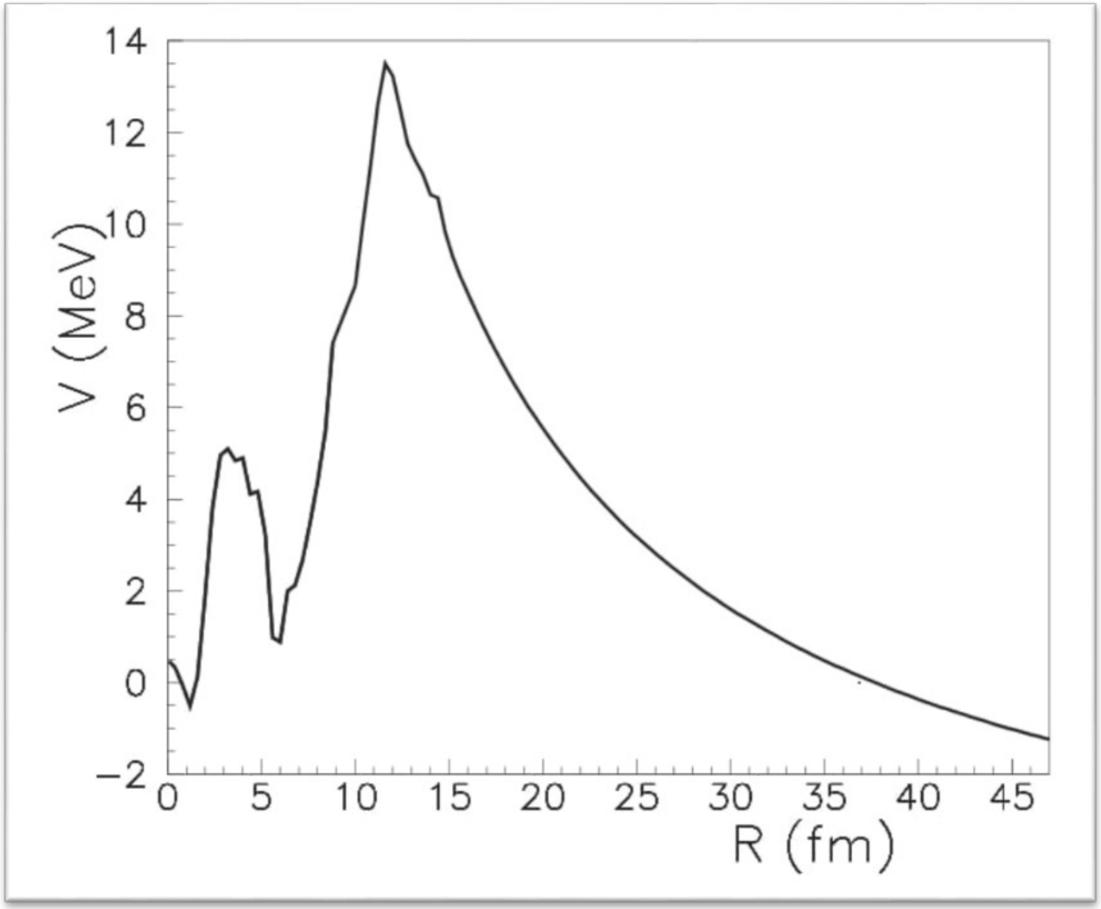
(a) Diamond-like (swollen) shapes

(b) Necked shapes

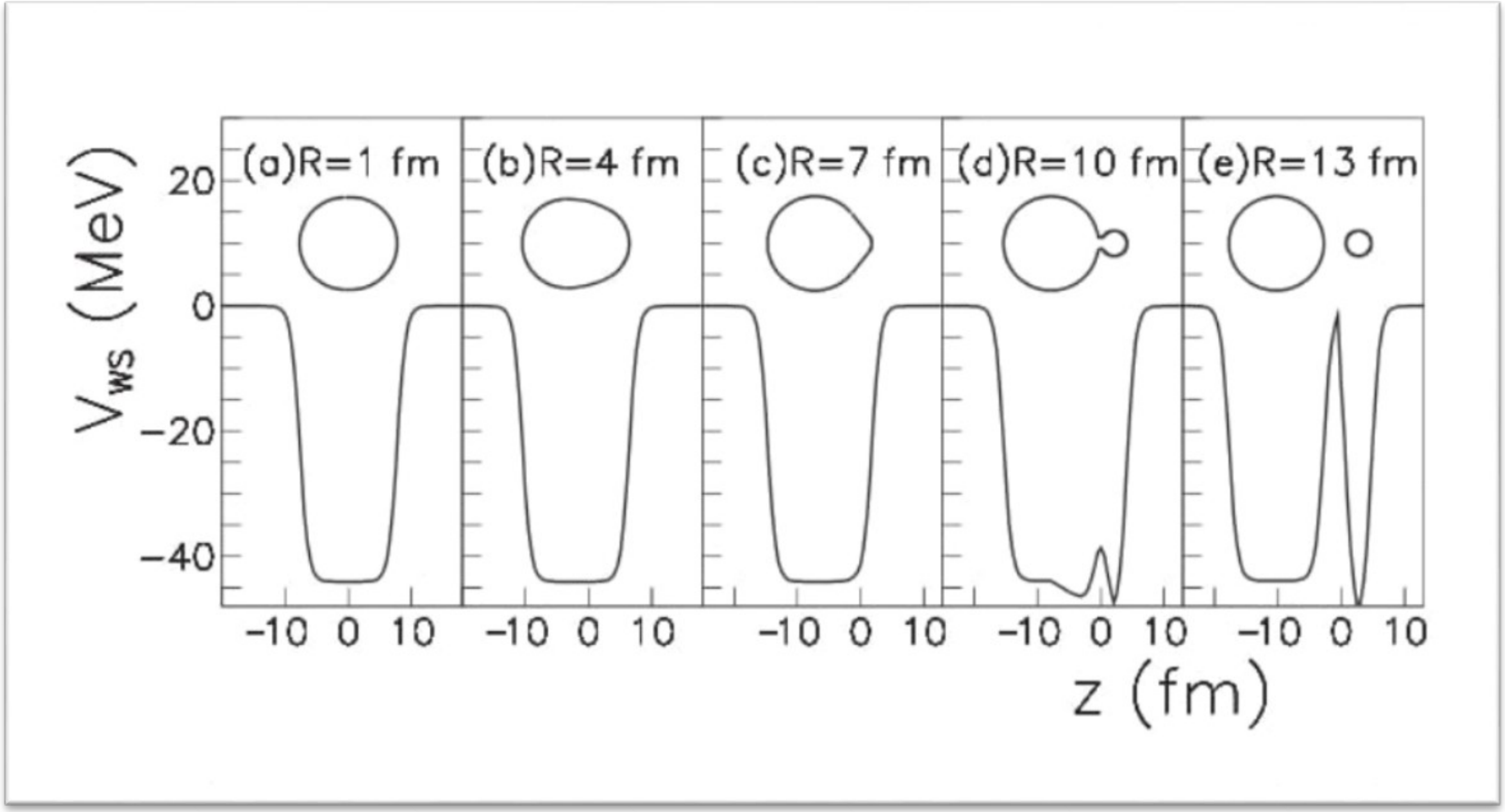
The ^{211}Po Case.
The alpha decay potential barrier along the least action path

$$P = \exp\left\{-\frac{2}{\hbar}\int_{R_i}^{R_f} \times \sqrt{2V(R,C,\eta)M\left(R,C,\eta,\frac{\partial C}{\partial R},\frac{\partial \eta}{\partial R}\right)}dR\right\}$$

M=Effective mass (cranking or GOA)
V=Deformation energy: macroscopic part given by Yukawa plus exponential and microscopic part given by Strutinsky prescriptions based on the Woods-Saxon TCSM.
A molecular minimum can be observed when the alpha particle is formed on the surface of the daughter. This minimum is due to the strong shell effects of the nascent ^{207}Pb.

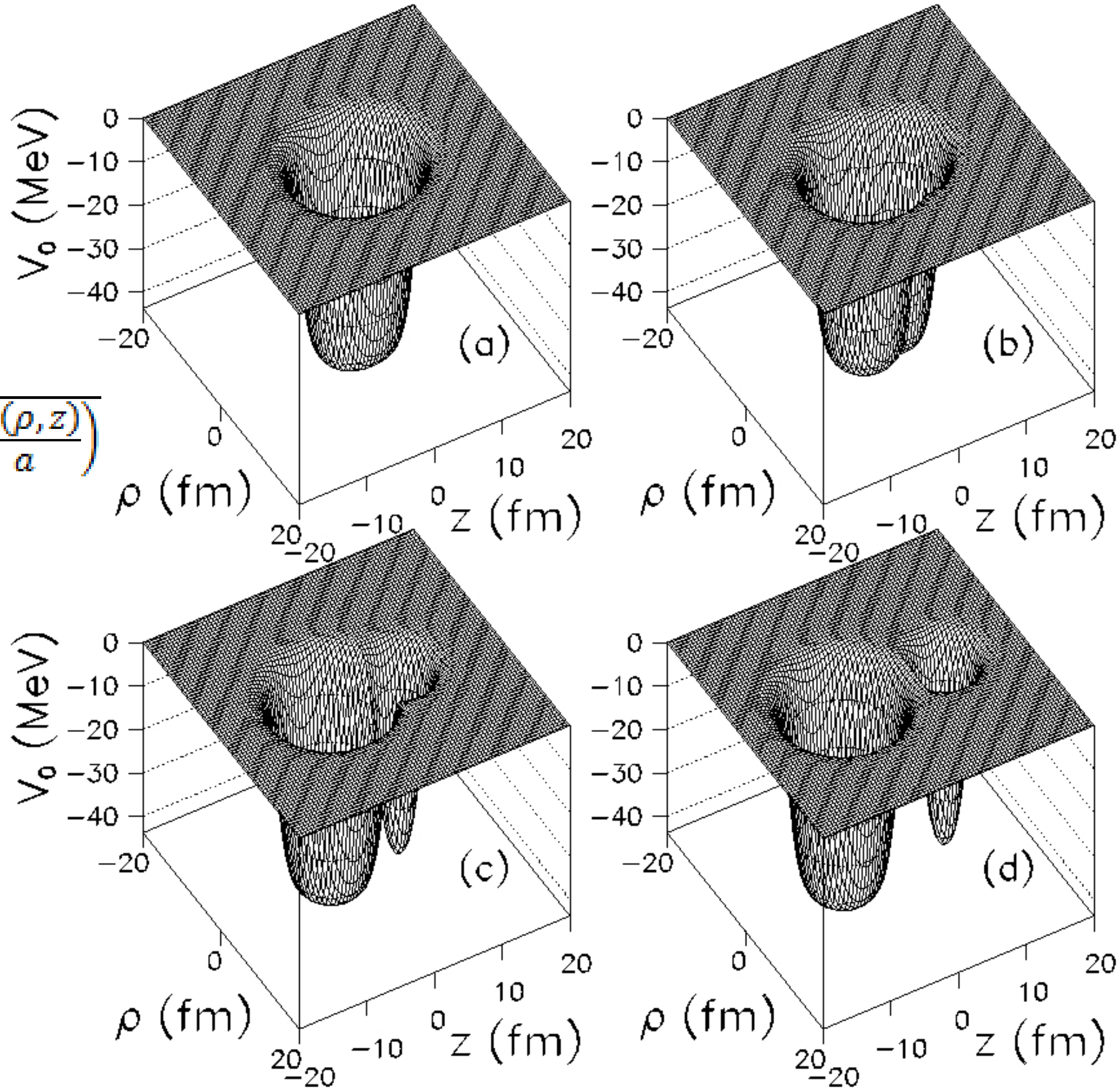


The Woods-Saxon potential and the shapes of the nuclear system for different elongations R



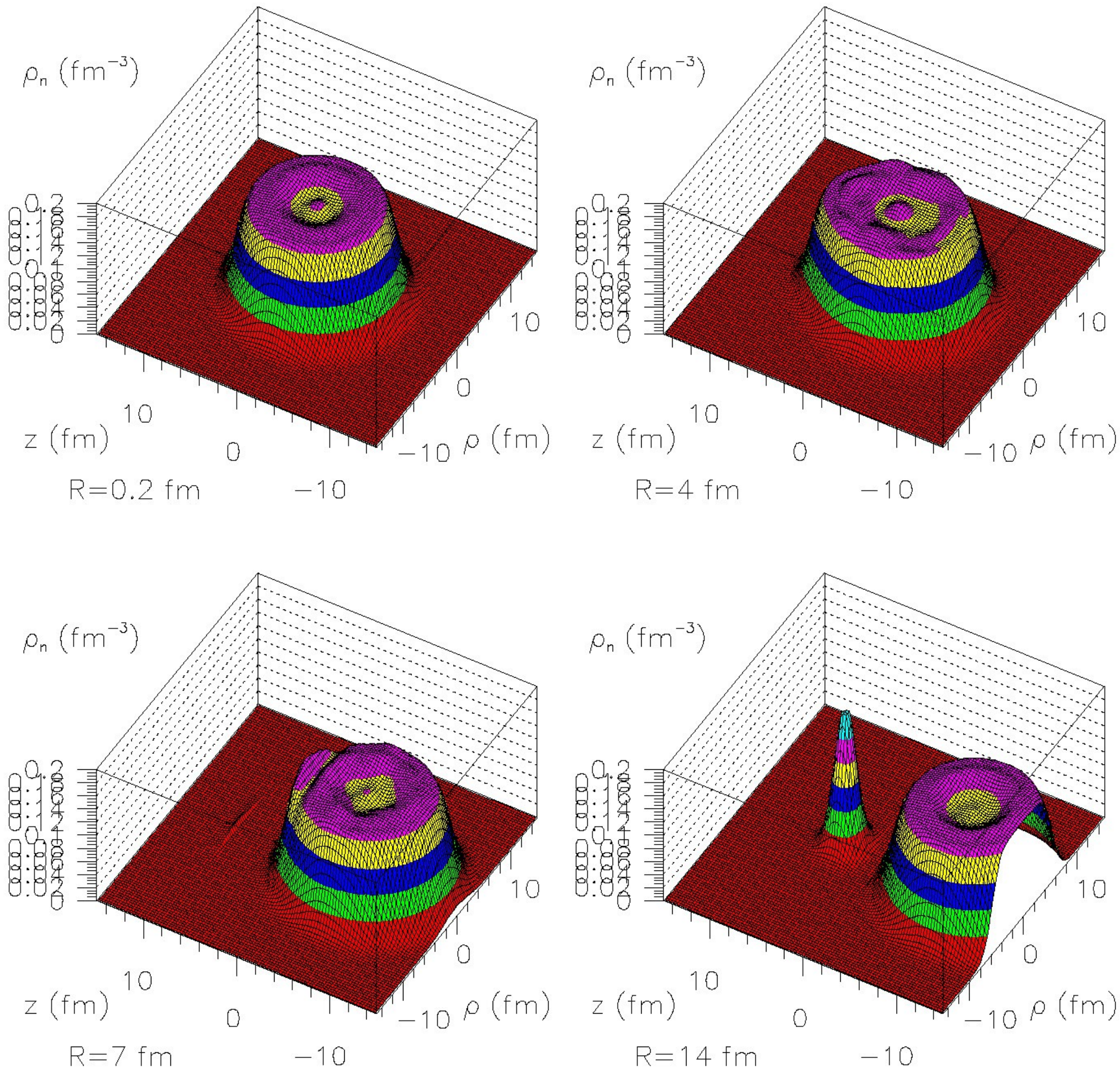
Woods-Saxon mean field potential within the two center parametrization

$$V(\rho,z) = -\frac{V_c}{1+exp\left(\frac{D(\rho,z)}{a}\right)}$$

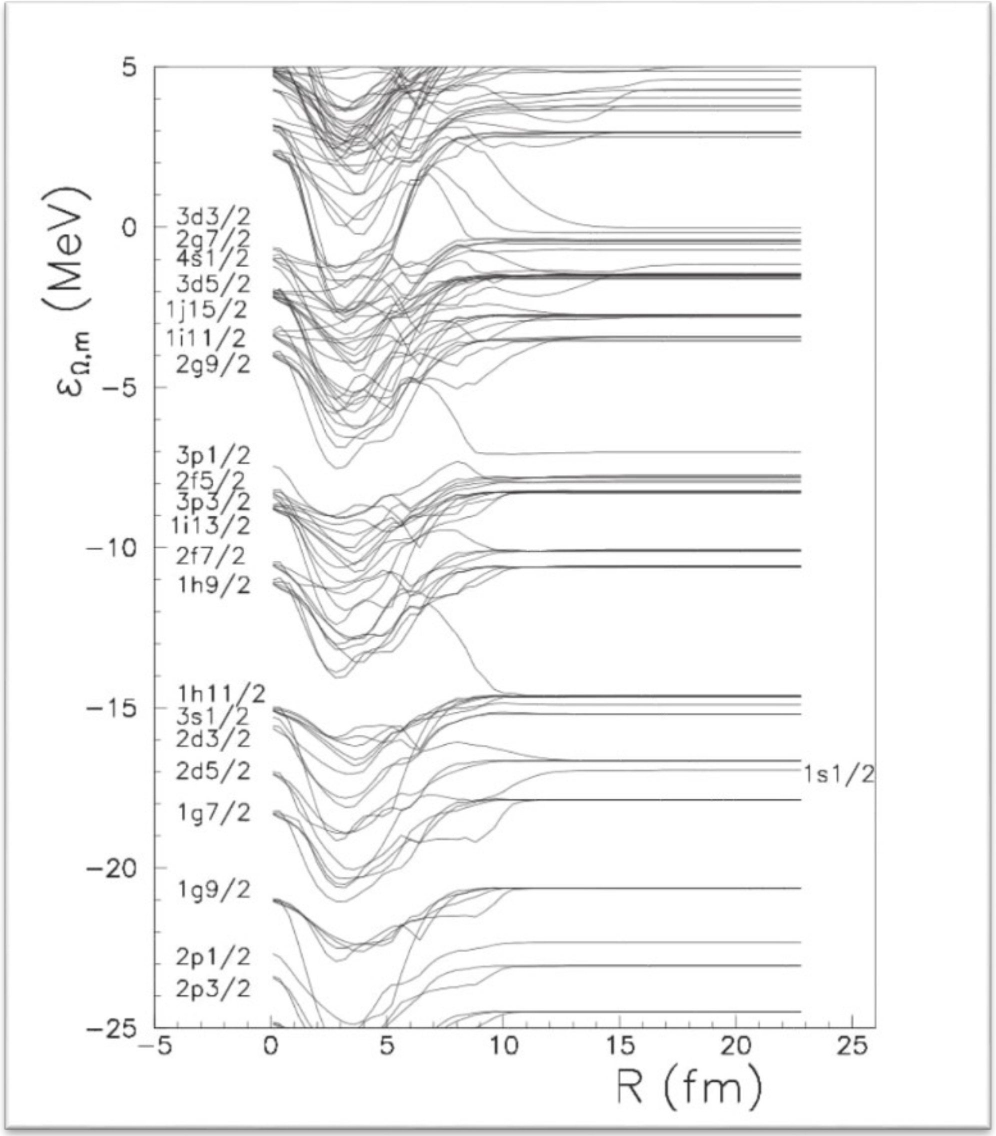


NUCLEAR DENSITY FOR THE ALPHA-DECAY PROCESS

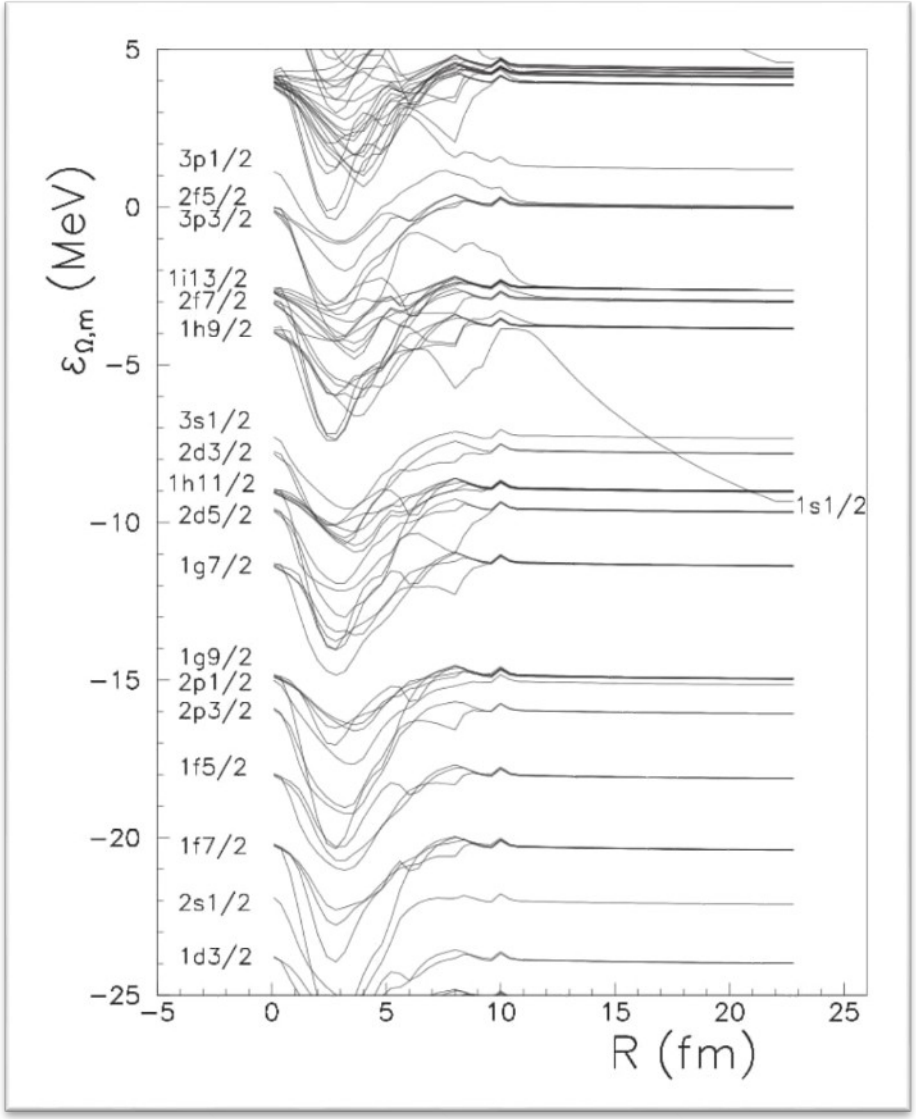
The system as a whole is perturbed.



Neutron single particles level scheme during the disintegration

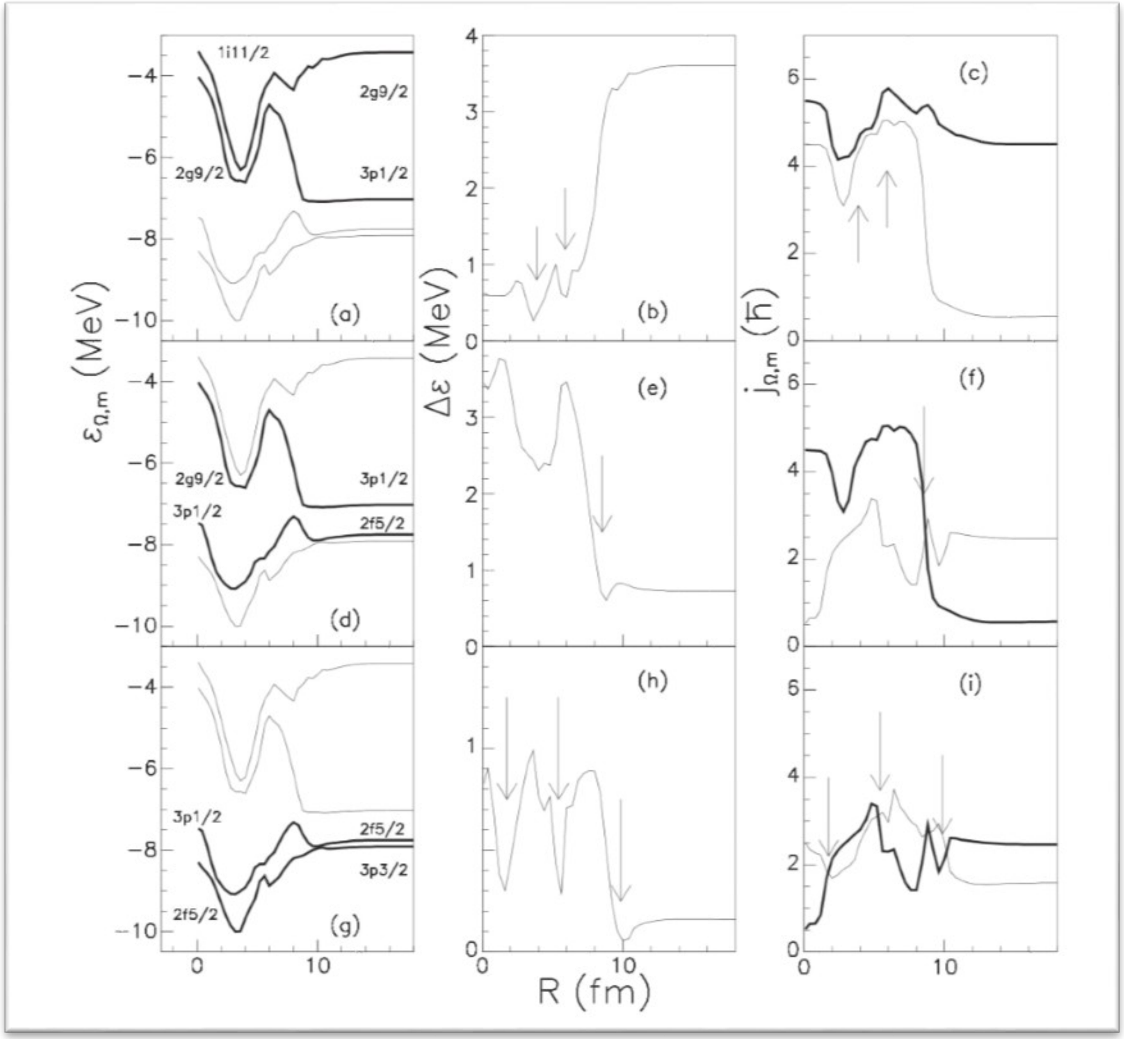


Proton single particles level scheme during the disintegration



Selected single particle energies Ω=1/2, differences and intrinsic angular momenta.

The single particle energies ε relative to the distance between the centers of the fragments.
The energy differences Δε between the selected levels.
The intrinsic angular momenta j(j+1)=<Ωm|j²|Ωm>. The projection of the spin is ½.



Values of the probabilities of different seniority one configurations at scission as solutions of equations (equivalent to preformation probabilities).

The internuclear Velocity is $v=2\times10^4$ fm/fs, leading to a long time for the barrier penetration of 1.7×10^{-18} s

Initial state	Final state	Ω	$P_{\Omega,m}$
$1i_{11/2}$	$2g_{9/2}$	1/2	0.102
$2g_{9/2}$	$3p_{1/2}$	1/2	9.553×10^{-2}
$3p_{1/2}$	$2f_{5/2}$	1/2	7.865×10^{-2}
$2f_{5/2}$	$3p_{3/2}$	1/2	8.323×10^{-2}
$1i_{13/2}$	$2f_{7/2}$	1/2	1.898×10^{-5}
$1i_{11/2}$	$1p_{3/2}$-α	3/2	0.207
$2g_{9/2}$	$2g_{9/2}$	3/2	0.1621
$2f_{5/2}$	$2f_{5/2}$	3/2	1.965×10^{-3}
$3p_{3/2}$	$3p_{3/2}$	3/2	1.952×10^{-2}
$1i_{13/2}$	$1i_{13/2}$	3/2	2.067×10^{-3}
$1i_{11/2}$	$1i_{11/2}$	5/2	0.1468
$2f_{5/2}$	$2f_{5/2}$	5/2	5.353×10^{-3}
$1i_{11/2}$	$1i_{11/2}$	7/2	9.661×10^{-2}
$2g_{9/2}$	$2g_{9/2}$	7/2	4.570×10^{-2}
$1i_{13/2}$	$1i_{13/2}$	7/2	1.162×10^{-8}
$1i_{11/2}$	$1i_{11/2}$	9/2	4.331×10^{-2}
$2g_{9/2}$	$2g_{9/2}$	9/2	4.841×10^{-3}
$1i_{13/2}$	$1i_{13/2}$	9/2	3.396×10^{-11}
$1i_{11/2}$	$1i_{11/2}$	11/2	3.977×10^{-8}
$1i_{13/2}$	$1i_{13/2}$	11/2	4.701×10^{-11}

Ground state of the parent nucleus is $[\pi(h_{9/2})^2\nu(g_{9/2})^1]_{9/2}+$

EXPERIMENT

98.9% transitions on the ground state 3p1/2 of the daughter nucleus

0.55% transitions on the first excited state 2f5/2 of the daughter nucleus

0.54% transitions on the second excited state 3p3/2 of the daughter nucleus

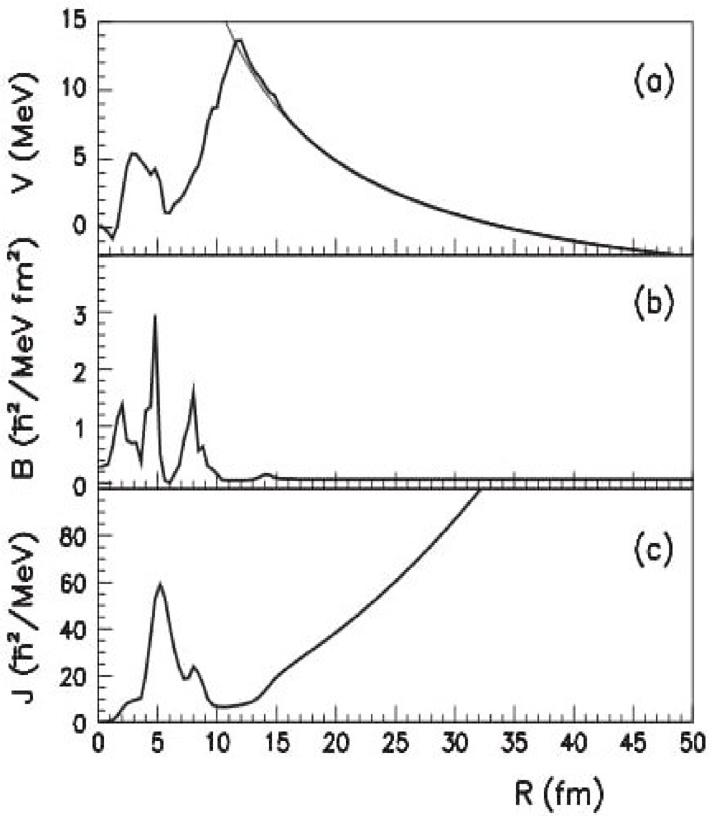
THEORY

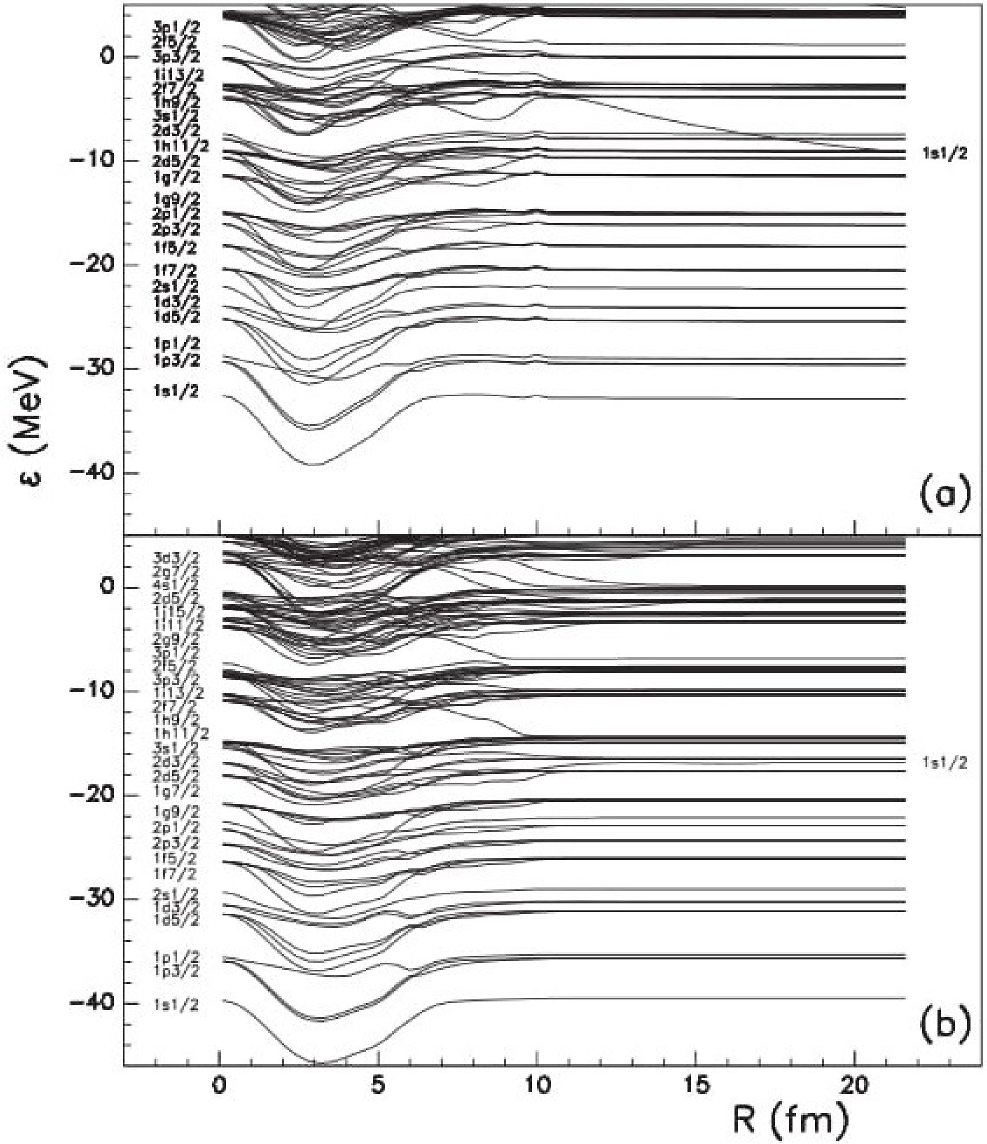
99.1% transitions on the ground state of the daughter

0.26% transitions on the first excited state of the daughter

0.62% transitions on the second excited state of the daughter

The ^{211}Bi Case: Potential barrier, effective mass and moment of inertia



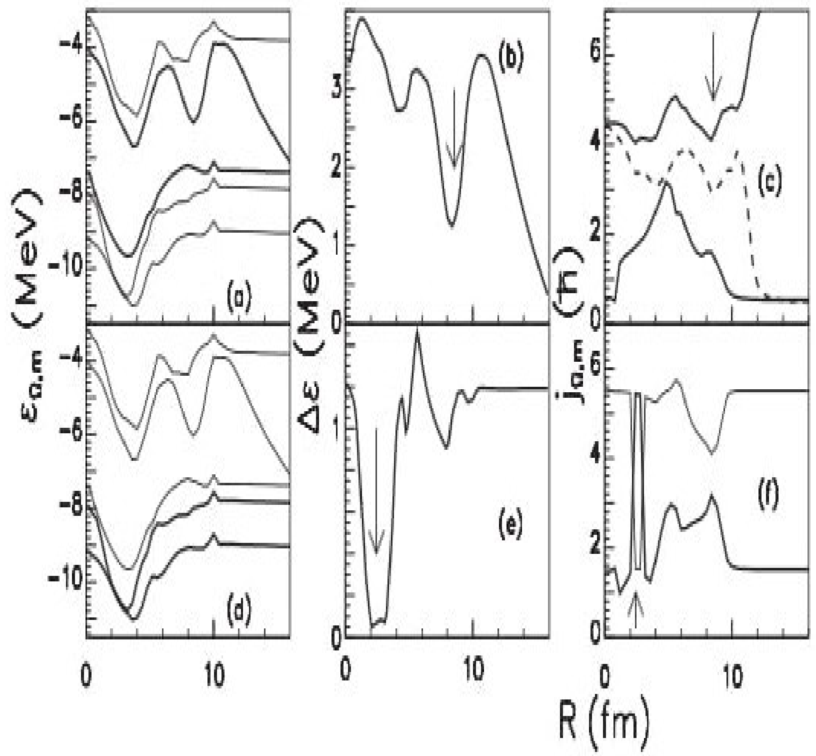


$^{211}Bi \rightarrow$ alpha+^{207}Tl
One proton above the closed shell. The proton adiabatic level of the alpha particle emerges from $1h_{9/2}$. The energy of this level is strongly affected by Coulomb polarization.

Fig. 2: Single-particle energies ϵ as a function of the internuclear distance R for proton and neutron in panels (a) and (b), respectively. The single-particle level of the α-cluster is marked on the right.

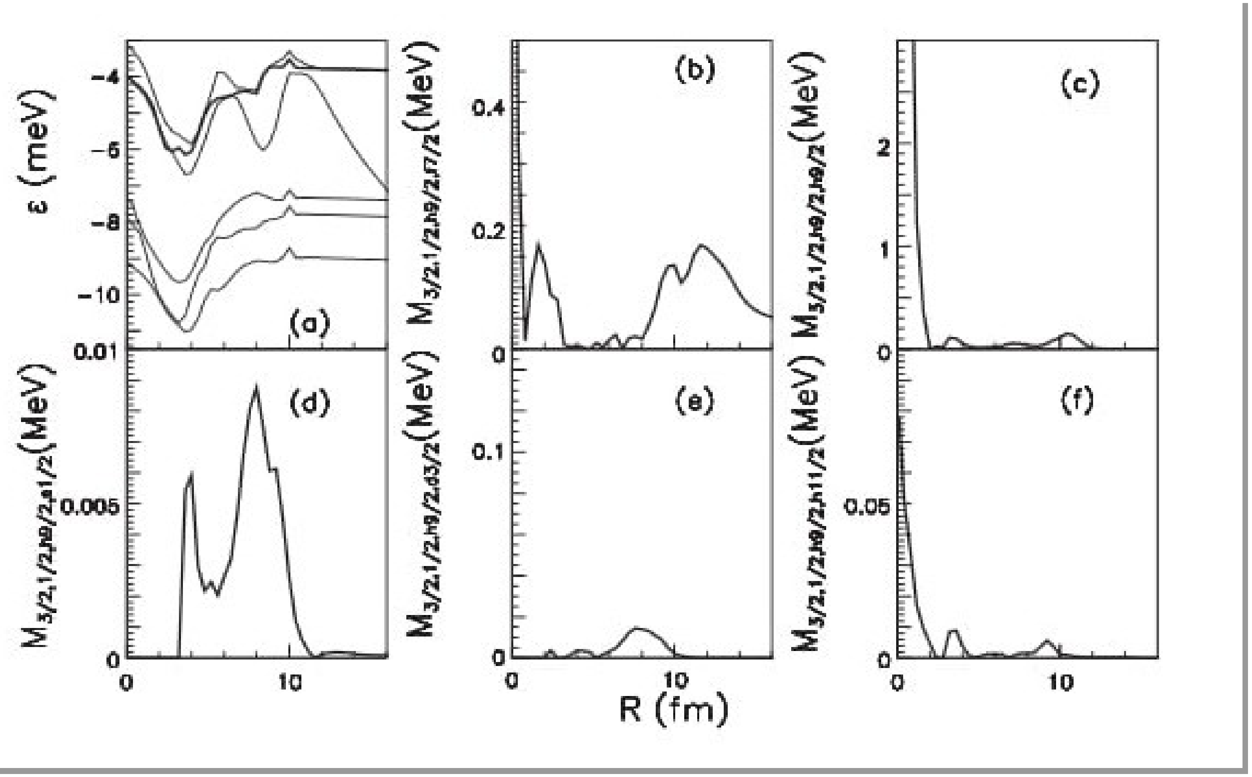
IDENTIFICATION OF AVOIDED CROSSING REGIONS

(a)(d)The single particle energies ε relative to the distance between the centers of the fragments. The selected pairs of levels ($1h_{9/2}$,$3s_{1/2}$) and ($2d_{3/2}$,$1h_{11/2}$) are plotted with thick lines. (b)(e)The energy differences Δε between the selected levels. (c)(f)The intrinsic angular momenta j(j+1)=<Ωm|j²|Ωm>. The projection of the spin is ½.

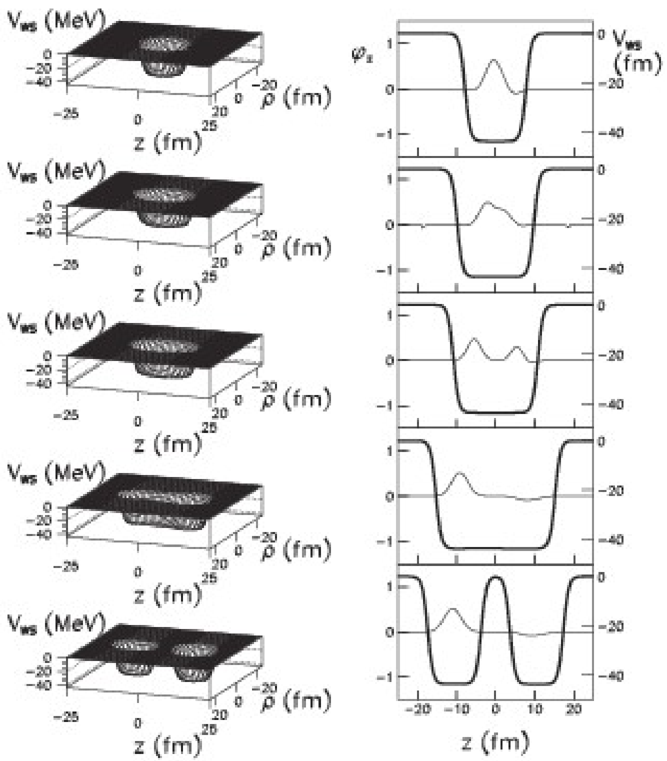


The Coriolis coupling matrix elements

The matrix elements of the Coriolis coupling $M=\hbar^2\langle\Omega+1,m'|j_+|\Omega,m\rangle/2J$ between the state $1h_{9/2}$ $\Omega=3/2$ and the states $\Omega=1/2$ ($2f_{7/2}$,$1h_{9/2}$,$3s_{1/2}$,$2d_{3/2}$ and $1h_{11/2}$)



UNFOLDING STATES IN PARTNER NUCLEI

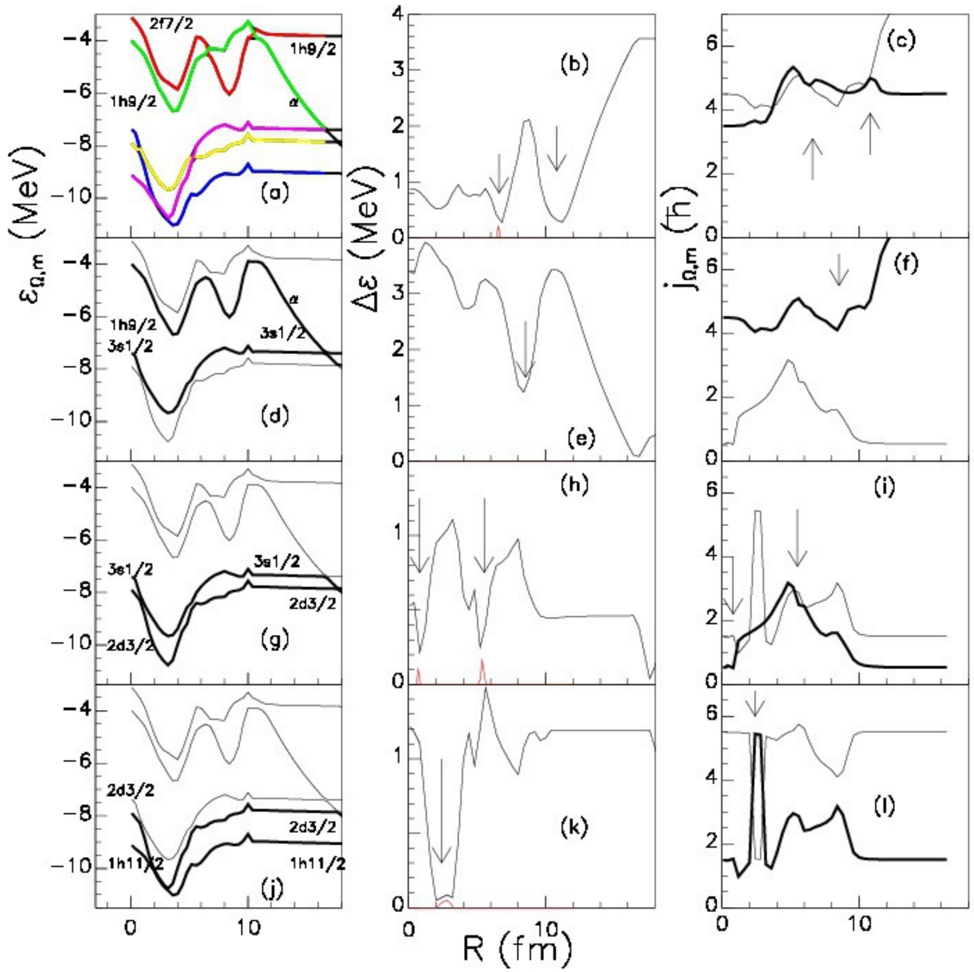


The potential and the lowest single particle wave function are represented for different values of the distance between the centers of the fragments.
Close to the scission region, the single particle wave function is localized in one of the two fragments. The probability to find the nucleon in one of the two region can be computed and a disentanglement of the wave functions can be obtained.
Using this prescription it is possible to introduce a condition in the time dependent pairing equations to project the number of particles in the two nuclei close to scission:

$$\delta\mathcal{L} = \delta\langle\varphi|H + H' - \lambda|N_2\hat{N}_1 - N_1\hat{N}_2| - i\hbar\frac{\partial}{\partial t}|\varphi\rangle.$$

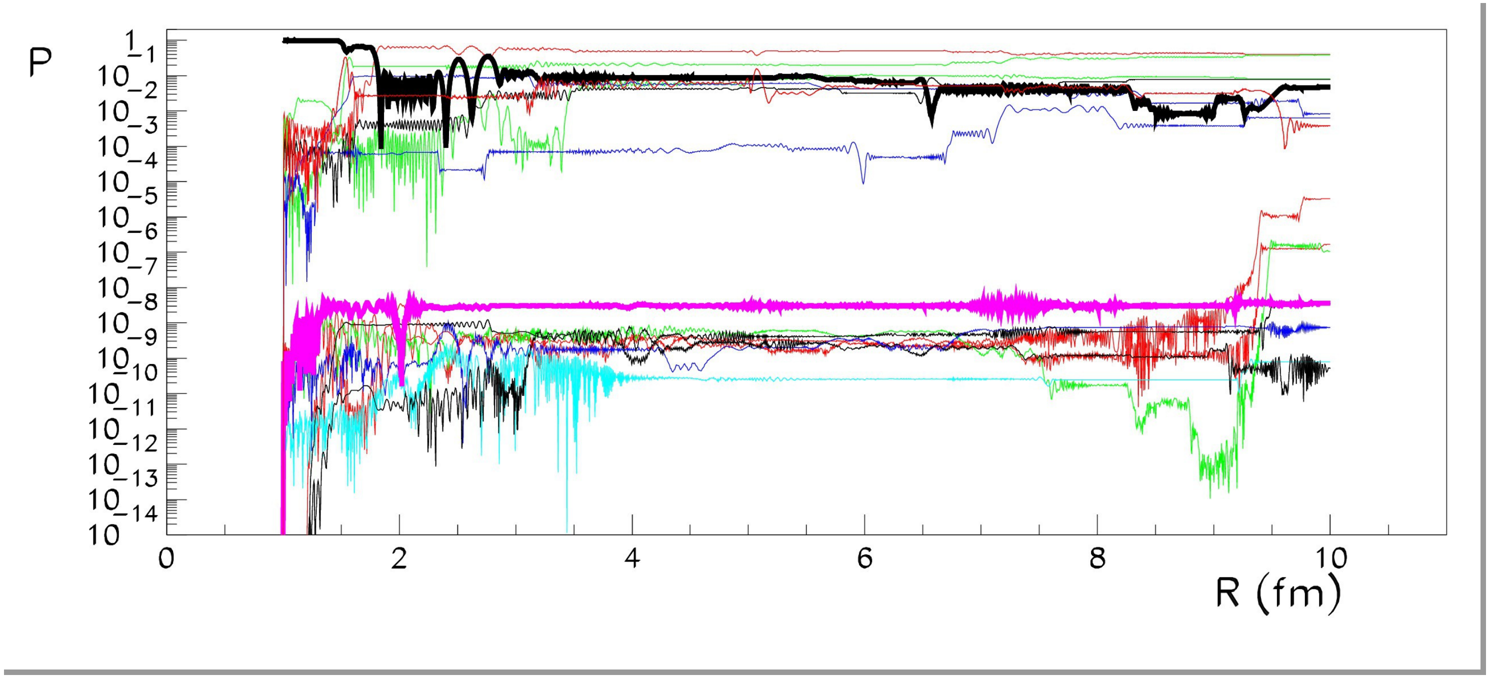
The diabatic levels for spin projection ½

The initial condition: ground-state at a deformation R=0.8 fm. The initial single particle state emerging from spherical orbital $1h_{11/2}$ arrives finally on the ground state $3s_{1/2}$ of the daughter.



Probabilities of different seniority-1 configurations relative to the distance between centers

Probabilities of occupation of unpaired diabatic levels. Thick black line-Ω=1/2: $1h_{9/2}$ initial state and final alpha particle level. Thick violet line-Ω=1/2: $3s_{1/2}$ final state (ground-state of Tl). Thin black lines Ω=1/2 states, thin red lines Ω=3/2 states, thin green lines Ω=5/2 states, thin dark blue lines Ω=7/2 states, thin blue line Ω=9/2 states.



Configuration probabilities, penetration probabilities and asymptotic specialization energies

Initial state m	Final state	Ω ($\hbar$)	$\lvert c_{\Omega,m}\rvert^2$	$P^b_{\Omega,m}$	$\Delta E_{\Omega,m}$ (Mev)
$2f_{7/2}$	$1h_{9/2}$	1/2	7.735×10^{-2}	1.90×10^{-74}	3.892
$1h_{9/2}$	$1s_{1/2}$ (α)	1/2	4.700×10^{-2}		
$3s_{1/2}$	$3s_{1/2}$	1/2	3.599×10^{-8}	2.66×10^{-36}	0
$2d_{3/2}$	$2d_{3/2}$	1/2	3.414×10^{-8}	7.17×10^{-39}	0.379
$1h_{11/2}$	$1h_{11/2}$	1/2	5.070×10^{-10}	1.55×10^{-53}	2.262
$2f_{7/2}$	$2f_{7/2}$	3/2	0.3951	2.45×10^{-92}	4.833
$1h_{9/2}$	$1h_{9/2}$	3/2	3.787×10^{-3}	2.49×10^{-74}	3.892
$2d_{3/2}$	$2d_{3/2}$	3/2	1.647×10^{-6}	7.85×10^{-39}	0.379
$1h_{11/2}$	$1h_{11/2}$	3/2	3.253×10^{-5}	2.02×10^{-53}	2.262
$2f_{7/2}$	$2f_{7/2}$	5/2	0.3817	2.89×10^{-92}	4.833
$1h_{9/2}$	$1h_{9/2}$	5/2	8.042×10^{-2}	4.08×10^{-74}	3.892
$1h_{11/2}$	$1h_{11/2}$	5/2	1.030×10^{-6}	3.32×10^{-53}	2.262
$2f_{7/2}$	$2f_{7/2}$	7/2	8.211×10^{-3}	3.81×10^{-92}	4.833
$1h_{9/2}$	$1h_{9/2}$	7/2	6.380×10^{-3}	7.24×10^{-74}	3.892
$1h_{11/2}$	$1h_{11/2}$	7/2	7.410×10^{-9}	5.812×10^{-53}	2.262
$1h_{11/2}$	$1h_{11/2}$	9/2	7.805×10^{-10}	9.28×10^{-53}	2.262

Ground state of the parent nucleus $[\pi(h_{9/2})^1\nu(g_{9/2})^2]_{9/2^-}$

EXPERIMENT

87.901% transitions on the ground state 3s1/2 of the daughter nucleus

12.098% transitions on the first excited state 2d3/2 of the daughter nucleus

6.35×10^{-15}% transitions on the second excited state 1h11/2 of the daughter nucleus

THEORY

83.77% transitions on the ground state of the daughter

16.23% transitions on the first excited state of the daughter

<0.0019% transitions on the second excited state of the daughter

RESUME

In alpha decay, sometimes the daughter nucleus is left in an excited state. This phenomenon was observed experimentally and was called fine structure. By considering that the parent nucleus deforms during the disintegration process, the single particle states are reorganized. The modifications of the internal states produces some inherent dynamical excitations due to the Landau-Zener promotion mechanism and due to the Coriolis coupling. These microscopic interactions lead to excitations of the daughter nucleus, and therefore manage the fine structure of the process.

IN CONCLUSION, a new set of time-dependent coupled channel equations derived from the variational principle is proposed to determine dynamically the mixing between different seniority one configurations. The time dependent pairing equations (similar to the time dependent Hartree-Fock-Bogoliubov equations) are generalized by including the radial and the angular couplings. These equation explained the fine structure of alpha decay.

THANK YOU